Tracking Water Entrainment in Nuclear Detonations

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Abstract

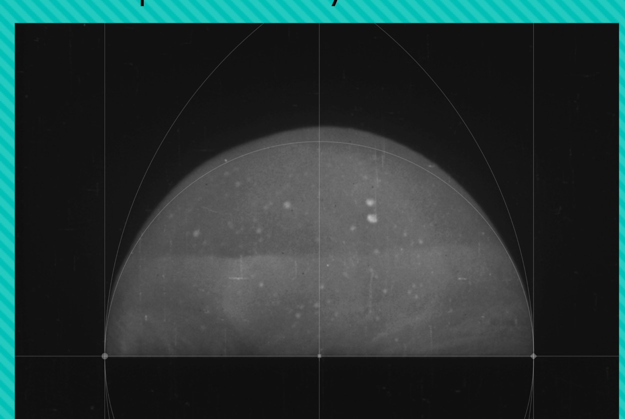
During the era of Nuclear testing, the U.S. government detonated 36 weapons over water. Barge shots (films of detonations over water), have not been studied as extensively as shots over land. We studied barge shots this summer, and we noticed that on all shots with yields of 100 kt or larger, a mysterious line appeared on the films. We found that for all yields, the ratio of the elevation of the entrainment line to the elevation of the fireball evolved similarly with time. By looking into previous studies, we were also able to confirm that the water entrainment line was caused by fine mist circulated above the fireball. Studying these shots gives us a unique opportunity to study Mach 100 shock waves interacting with water, which is not something that can be studied within the walls of a laboratory.

Research Objectives

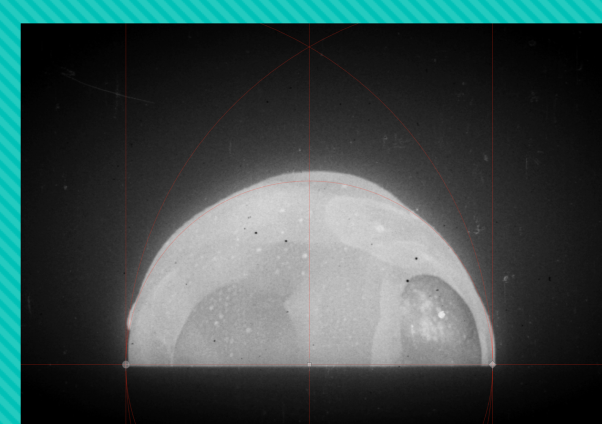
- Study high Mach speed shock wave interacting with water.
- Measure the time evolution of the water entrainment line.
- Determine the optical effects which cause the water entrainment line.

Motivation

- We observed a previously unnoticed horizontal line within the outline of the shock wave on films of detonations with yields of 100 kt and over.
- This water entrainment line can potentially explain the asymmetry in barge shots we previously did not understand.



Dakota, 1,100 kt. Water entrainment and asymmetry.



Butternut, 81 kt. No water entrainment, symmetric

- Studying these detonations over water provides a unique opportunity to study the effects of a Mach 100 shock wave interacting with water.

*Mach 100: 100 times faster than the speed of sound.

Methods

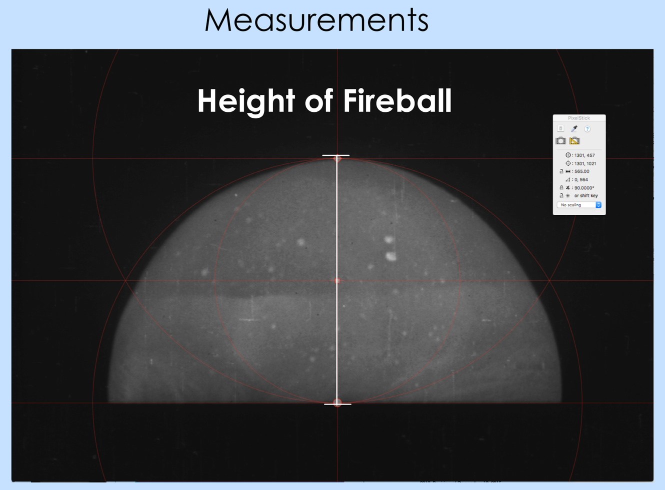
- Used PixelStick (a computer app) to measure the vertical radius, the horizontal diameter, and the height of the water entrainment line in pixels.
- Determined absolute time scale for each film using timing mark analysis.
- Calculated when the shock wave temperature reached 3300 K with:

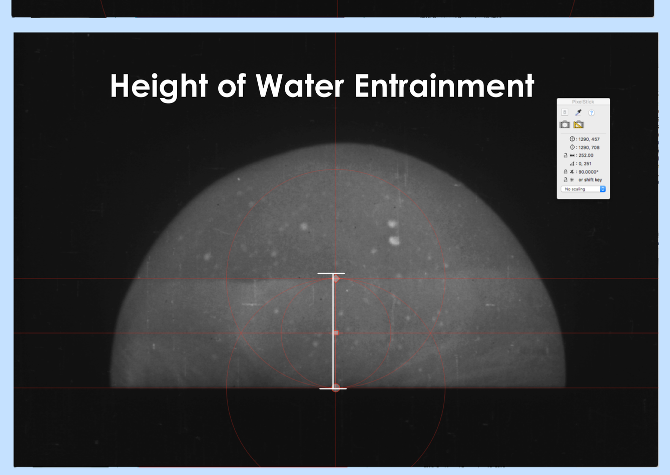
$$T_{3300} = 0.004056 \cdot \left(\frac{\theta * Y_{sw}}{\rho_\circ}\right)^{1/3} *$$

- Calculated "relative time" by dividing absolute time by the time at which the shockwave cools to a temperature of 3300 K.

$^*\theta$ = Geometric Factor Y_{SW} = Yield transferred to shockwave
$\rho_\circ$ = Ambient air density

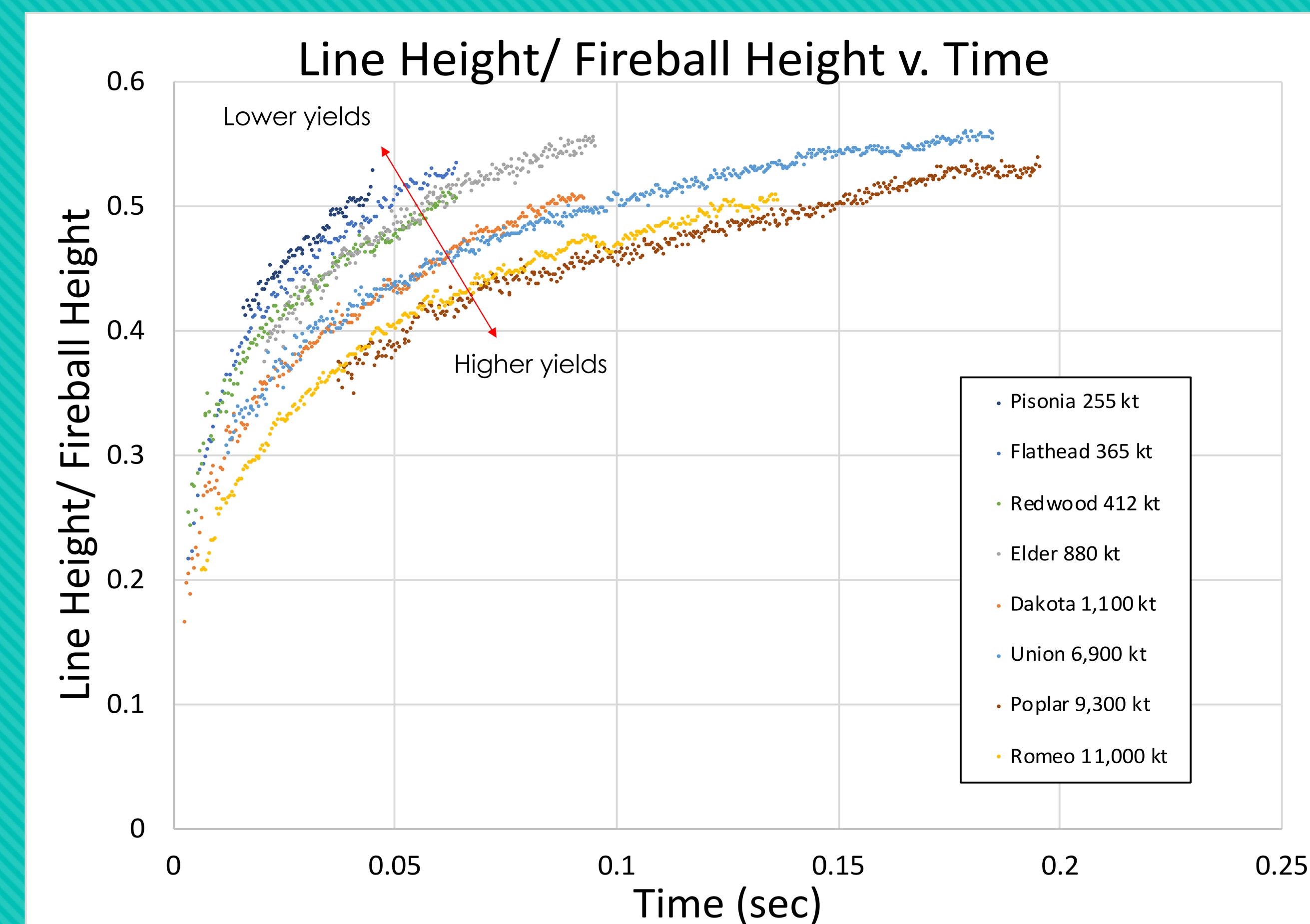
Measurements





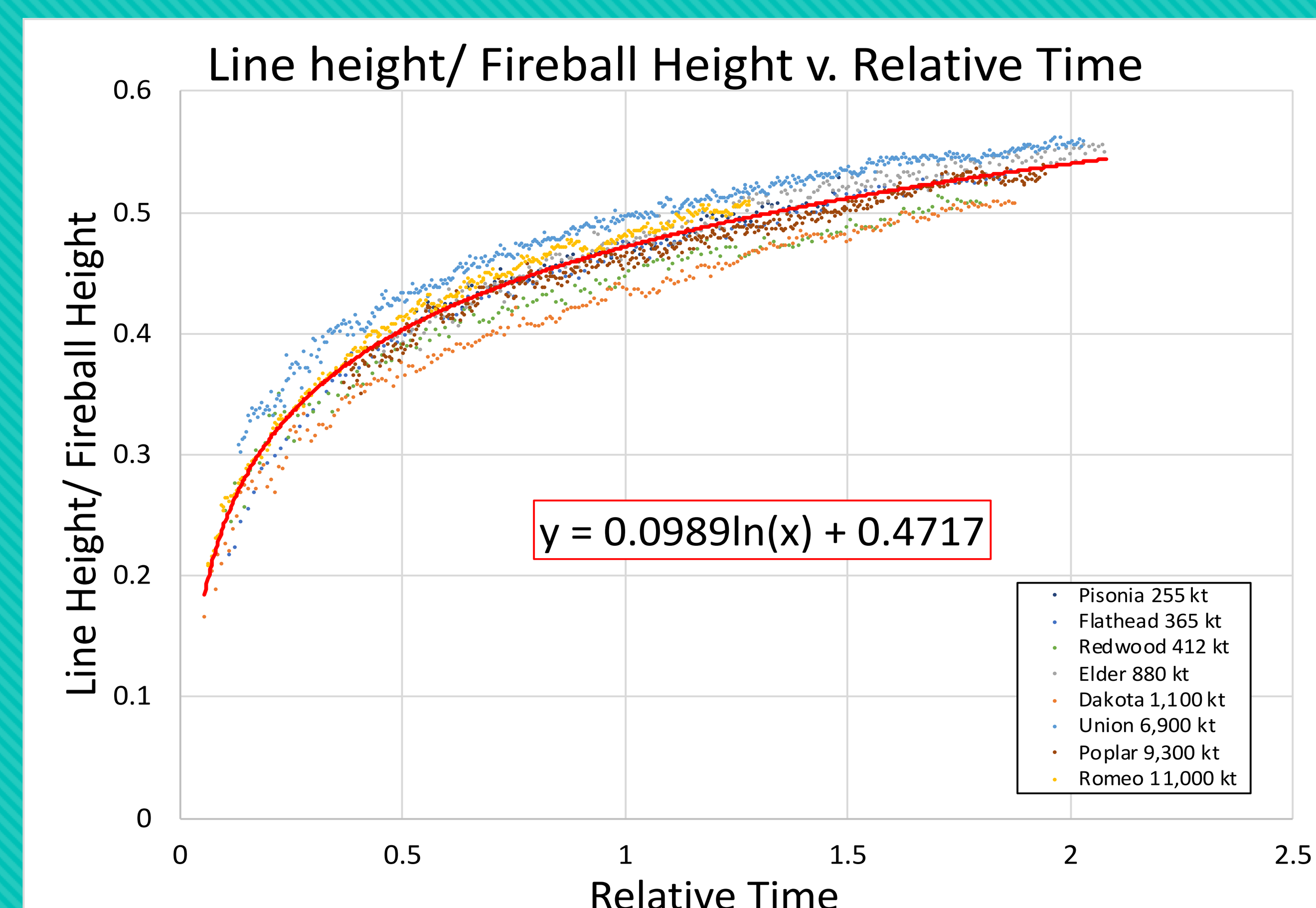
Results

-Evolution of the Entrainment Line to Fireball Height Ratio



Line Height to Fireball Height Ratio versus Time

- The ratio of the entrainment line height to the fireball height seems to evolve in a similar logarithmic shape regardless of yield.
- Lower yield shots tend to have higher ratio curves.
- The layering of the ratio curves is not always consistent with the magnitude yield value, which shows that yield may not be the only variable affecting the ratio.



Line Height to Fireball Height Ratio versus Relative Time

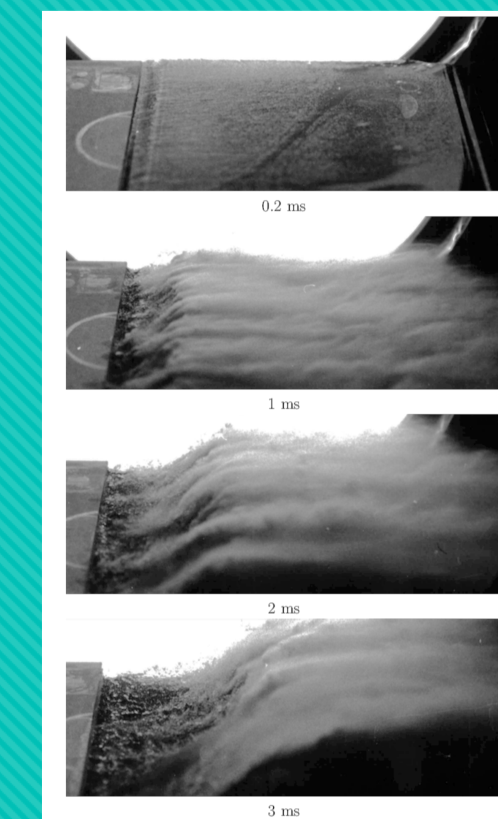
- Higher yield explosions take longer to go through the fireball evolution.
- Relative time normalizes the evolution of the fireball by creating a time scale relative to the point when each fireball reaches 3300 K.
- The ratio curves of the detonations of different yields all seem to be converging to one average logarithmic curve.

The line height ratio evolves logarithmically with time. The average ratio evolution follows the curve

Line height ratio= $0.0989\ln(relative\ time) + 0.4717$.

Note: Dr. Gregory Spriggs' project is in the process of re-evaluating the yields of all the weapons tested during the cold war. It is our hope that this re-evaluation will unveil a clearer average line height ratio curve against relative time and a more consistent layering pattern when the line height ratio is plotted vs absolute time.

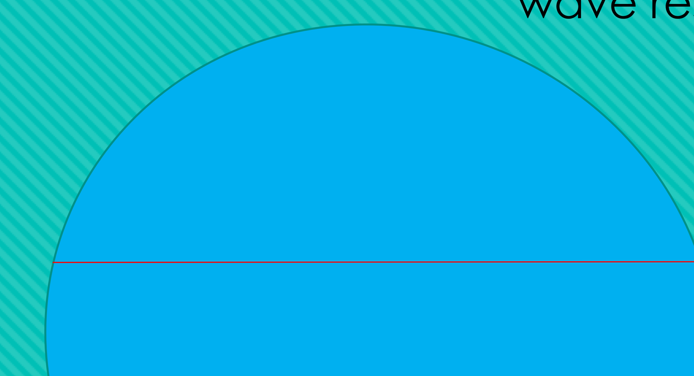
Discussion



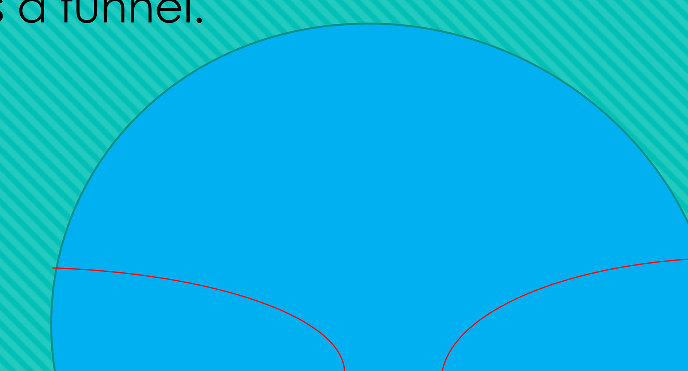
Teodorczyk and Shepherd's shock wave creating mist

- An article by Andrzej Teodorczyk and Joseph E. Shepherd on the interaction of a shock wave with a water layer assisted in determining the cause of the water entrainment line.
- In Teodorczyk and Shepherd's experiment, the shock wave raised fine droplets into the air. These droplets simulate the water entrainment in barge shots.
- The shockwave formed a wave which created a mist cloud.
- When the downward component of the shockwave initially strikes, it pushes the water radially outward.

Because of mist height measurements in Teodorczyk and Shepherd's research, we can assume that the water entrainment inside the shock wave resembles a funnel.



The entrainment line from outside the fireball



Predicted cross sectional view of the entrainment line

This research is important because it was the first time the water entrainment line had been seen or studied in nuclear detonations, and these films present the only opportunity to study well documented events that recorded high Mach number shockwaves travelling over water. Findings from these studies can be translated into a better understanding of observed detonations over water and might also help with models of high mass objects from space striking our oceans.

Future Work

- Re- plot the data once the yields have been verified.
- Further analyze the similarities and differences between low and high Mach speed shockwaves.
- Measure the exact speed of the shock waves and develop a correlation between mist height and shock wave speed.
- Discover why the line only appears in detonations of 100 kt or more.

References

Andrzej Teodorczyk and Joseph E. Shepherd, Interaction of a Shock Wave with a Water Layer, Explosion Dynamics Laboratory Report FM2012.002 , May 2012. Revision of December 13, 2015

This work was performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under Contract DE-AC52-07NA27344

LLNL-POST-756113